

A hand holding a magnifying glass over a desk. The magnifying glass focuses on a globe of the Earth. Surrounding the globe are various white icons on a dark background, including a smiley face, a rocket, a person, a flower, a car, a person with a bag, a person with a speech bubble, a person with a no symbol, a person with a gear, a person with a lightbulb, a person with a magnifying glass, a person with a target, a person with a heart, a person with a star, a person with a moon, a person with a sun, a person with a cloud, a person with a rain cloud, a person with a lightning bolt, a person with a snowflake, a person with a fire, a person with a water drop, a person with a leaf, a person with a recycling symbol, a person with a biohazard symbol, a person with a radiation symbol, a person with a chemical symbol, a person with a medical symbol, a person with a legal symbol, a person with a financial symbol, a person with a social symbol, a person with a communication symbol, a person with a technology symbol, a person with a science symbol, a person with a nature symbol, a person with a culture symbol, a person with a history symbol, a person with a geography symbol, a person with a language symbol, a person with a mathematics symbol, a person with a physics symbol, a person with a chemistry symbol, a person with a biology symbol, a person with a psychology symbol, a person with a sociology symbol, a person with a political symbol, a person with a religious symbol, a person with a philosophical symbol, a person with a literary symbol, a person with a musical symbol, a person with a theatrical symbol, a person with a sporting symbol, a person with a recreational symbol, a person with a health symbol, a person with a wellness symbol, a person with a fitness symbol, a person with a diet symbol, a person with a sleep symbol, a person with a stress symbol, a person with a mood symbol, a person with a personality symbol, a person with a behavior symbol, a person with a habit symbol, a person with a trait symbol, a person with a characteristic symbol, a person with a quality symbol, a person with a quantity symbol, a person with a degree symbol, a person with a unit symbol, a person with a measurement symbol, a person with a calculation symbol, a person with a formula symbol, a person with a theorem symbol, a person with a law symbol, a person with a principle symbol, a person with a rule symbol, a person with a guideline symbol, a person with a standard symbol, a person with a norm symbol, a person with a convention symbol, a person with a custom symbol, a person with a tradition symbol, a person with a custom symbol, a person with a tradition symbol, a person with a custom symbol, a person with a tradition symbol. The desk also has a calculator, a pen, a small car, a flask with blue liquid, a spray bottle, and a clipboard with a pen.

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www.multispectrum.org

Edition: First

Year: March 2026

ISBN: 978-81-999601-7-6

DOI: 10.65647/msp/108/2026

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© Publisher

Publisher



(International Publisher)

Kanyakumari, Tamilnadu, India.

Branch: Chennai & Australia

Phone: +91 6384730258

E-Mail: editor@multispectrum.org

www.multispectrum.org

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Climate Change Projections Using CMIP6 Models and Shared Socioeconomic Pathways: Advances and Implications for Hydrological Systems

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Abstract

Climate change is increasingly influencing global and regional hydrological processes through alterations in temperature, precipitation, and extreme events. The Coupled Model Intercomparison Project Phase 6 (CMIP6) represents the latest advancement in climate modeling, providing improved simulations of Earth system processes and future climate projections under shared socioeconomic pathways (SSPs). This chapter presents a comprehensive overview of CMIP6 models and SSP scenarios, with a focus on their application in hydrological assessments. It discusses projected changes in key climatic variables and their implications for streamflow, groundwater recharge, evapotranspiration, and water resource sustainability. The chapter also highlights methodological challenges, uncertainties, and future research directions, emphasizing the need for integrated modeling approaches in climate impact studies.

Keywords

CMIP6, SSP Scenarios, Climate Models, Hydrological Cycle, Climate Change, Water Resources

1. Introduction

Climate change plays a crucial role in causing variations in the Earth's water cycle and affects key processes, such as rainfall, evapotranspiration, soil moisture levels, and runoff creation. Both observational data and modeling research have consistently shown that increasing global temperatures and shifts in atmospheric circulation patterns impact the amount and distribution of water resources ([Yalcin, 2024](#)). These alterations have significant consequences for water security, the sustainability of ecosystems, and socioeconomic progress. Climate models are crucial for comprehending historical climate fluctuations and predicting future shifts. In recent decades, the Coupled Model Intercomparison Project (CMIP) has coordinated modeling efforts that have greatly enhanced the depiction of climate processes ([Durack et al., 2025](#)). The most recent phase, CMIP6, integrates sophisticated Earth system components, such as dynamic vegetation, biogeochemical cycles, and refined cloud–aerosol interactions, thereby improving the accuracy of climate forecasts. An important advancement in CMIP6 is the incorporation of shared socioeconomic pathways (SSPs), which connect socioeconomic development paths with greenhouse gas emission scenarios. This framework allows for a more thorough evaluation of future climate risks and their effects on both natural and human systems.

2. CMIP6 Climate Models: Structure and Advancements

CMIP6 includes a collection of advanced global climate models (GCMs) and Earth system models (ESMs) created by leading research organizations around the world. These models replicate the interactions among the atmosphere, ocean, cryosphere, and land surface, integrating intricate feedback mechanisms that control climate variability.

Compared to previous phases, such as CMIP5, CMIP6 models include several key advancements:

- Improved spatial resolution enables better representation of regional climate features.
- Enhanced parameterization of cloud microphysics and aerosol processes, thereby reducing biases in the radiation balance
- Integration of carbon cycle and biogeochemical feedbacks, permitting dynamic simulation of greenhouse gas concentrations.
- Improved representation of land–atmosphere interactions is crucial for hydrological modeling.

CMIP6 introduces standardized experiments under the Diagnostic, Evaluation, and Characterization of Klima (DECK) and Scenario Model Intercomparison Project (ScenarioMIP), ensuring consistency across models. Multi-model ensemble approaches are commonly used to reduce uncertainty and improve robustness of projections. ([Yao et al., 2021](#))

3. Shared Socioeconomic Pathways (SSPs)

The SSP framework provides a set of internally consistent socioeconomic narratives that describe future global development pathways. These pathways are combined with radiative forcing targets to generate climate projections ([Morris et al., 2025](#)).

Key SSP scenarios include the following:

- **SSP1–2.6 (Sustainability):** Low emissions with strong environmental policies.
- **SSP2–4.5 (Middle of the road):** An intermediate pathway with moderate mitigation efforts.
- **SSP3–7.0 (Regional Rivalry):** High emissions resulting from fragmented global development.
- **SSP5–8.5 (fossil-fueled development):** Very high emissions driven by intensive energy use.

Among these, SSP2–4.5 and SSP5–8.5 are widely used in hydrological studies to represent moderate and extreme climate change scenarios, respectively. These scenarios differ significantly in projected temperature increases, precipitation variability, and the frequency of extreme events.

4. Climate Projections under CMIP6

4.1 Temperature Projections

According to the CMIP6 models, there is a consistent prediction of an increase in global average surface temperature across all SSP scenarios. The extent of this warming varies depending on the scenario, with SSP5–8.5 showing the greatest increase. Additionally, warming tends to be more pronounced over land areas owing to feedback mechanisms between the land and atmosphere.

4.2 Precipitation Variability

Anticipated shifts in precipitation patterns show considerable spatial variation. Some areas are likely to experience an increase in rainfall, whereas others may experience notable decreases. The intensity and timing of precipitation changes are crucial for hydrological systems, as they affect runoff production and water availability.